

## 9.5 Life Sensitivity Analysis for Hole Repair

Because holes are stress concentration sites, it is not surprising that a large number of holes are drilled oversize and repaired to remove crack indications identified during inspection. It is not possible to conduct a detailed damage tolerance analysis on every repair of this type; however, engineers can assess the life of many components before and after the hole is enlarged using Equation 9.3.1 and its integral counterpart Equation 9.3.12. Detailed evaluations should always be conducted for critical locations; in some cases, the detailed evaluations will become the building blocks for other simplified repair analyses.

Hole repairs are made to remove crack indications from the edge of the hole. Several example damage tolerance analyses are presented in this section to summarize the effect of oversizing the hole to remove some (but not all) of the crack damage. Practically speaking, the objective is to remove all the crack damage. But, because non-destructive evaluation (NDE) capability is what it is, the analyst can not presume that all traces of the crack are removed when the hole is oversized. From an economics and safety viewpoint, all traces of the crack should be removed and the aircraft restored to its original condition. When conducting a damage tolerance analysis to protect safety, it is wise to error on the conservative side in defining the initial crack size after a hole oversizing operation.

Before introducing the example analyses, it is instructive to review the integral counterpart of Equation 9.3.1, i.e. Equation 9.3.12, which is presented as Equation 9.5.1

$$F = \int_{a_o}^{a_f} \frac{da}{CK^p} \quad (9.5.1)$$

or

$$F = \frac{1}{C(\bar{\sigma}\sqrt{\pi})^p} \int_{a_o}^{a_f} \frac{da}{(\beta\sqrt{a})^p} \quad (9.5.2)$$

The parameter  $\beta$  is the geometry correction factor that is normally a function of crack length. We again note that the integral

$$I = \int_{a_o}^{a_f} \frac{da}{(\beta\sqrt{a})^p} \quad (9.5.3)$$

is dependent of stress effects and is only dependent on the geometry of the structure and of the crack. So if the stress parameter, i.e., the stress history, is constant, then the impact of geometry changes on life can be assessed by studying the variation of  $I$  as the geometry changes. The following example will be used to illustrate this point.

### EXAMPLE 9.5.1 Variation of Initial Crack Size on Life

A structural member made from D6AC steel has been experiencing cracking problems at a ¼ inch diameter weep hole. If the crack growth rate per flight hour is given by:

$$\frac{da}{d(FH)} = 1.6 \times 10^{-8} \bar{K}^{2.6}$$

then calculate the life required to grow a thru-thickness crack from several initial crack sizes to a 0.550 inch long radial crack. Assume the stress is 30 ksi.

SOLUTION:

The integral counterpart of the growth rate equation for this problem is

$$FH = \frac{1}{1.6 \times 10^{-8} (30\sqrt{\pi})^{2.6}} \int_{a_0}^{0.550} \frac{da}{(\beta\sqrt{a})^{2.6}}$$

where  $\beta$  is associated with the radially cracked hole geometry, (see Section 11):

$$\beta = 0.7071 + 0.7548y + 0.3415y^2 + 0.642y^3 + 0.9196y^4$$

where  $y = \frac{1}{1 + \frac{a}{r}}$

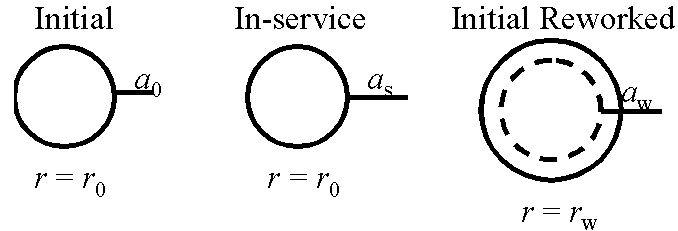
The life results for several initial crack lengths are presented in the following table.

Crack Growth Life as a Function of Initial Size for  $a_f = 0.550$  inch

$a_o$ (inch)	$\bar{\sigma} = 30$ ksi		$\bar{\sigma} = 50$ ksi	
	Life ( $L_{a_o}$ ) (Flight hours)	Life Ratio ( $L_{a_o} / L_{0.050}$ )	Life ( $L_{a_o}$ ) (Flight hours)	Life Ratio ( $L_{a_o} / L_{0.050}$ )
0.001	7715	1.48	2041	1.47
0.005	6720	1.29	1767	1.27
0.010	6364	1.22	1696	1.22
0.025	5806	1.11	1538	1.11
0.050	5220	1	1386	1
0.075	4796	0.92	1270	0.92
0.100	4395	0.84	1164	0.84
0.125	4023	0.77	1070	0.77

It is important to note that the life ratios generated by dividing all the life values by the life value associated with  $a_o = 0.050$  inch is independent of stress level, as shown by the results for  $\bar{\sigma}$  of 30 ksi and 50 ksi.

Equation 9.5.3 can also provide a simplified method for determining the effect of increasing the diameter of a cracked hole. Consider [Figure 9.5.1](#), which defines the three stages associated with increasing the hole diameter to remove a pre-existing crack. One of the first steps in the analysis is to obtain an estimate of the initial structural life (this life is referred to as the DTA result or the Blueprint life). For purposes of this analysis, the DTA result is presumed available for the region of interest.

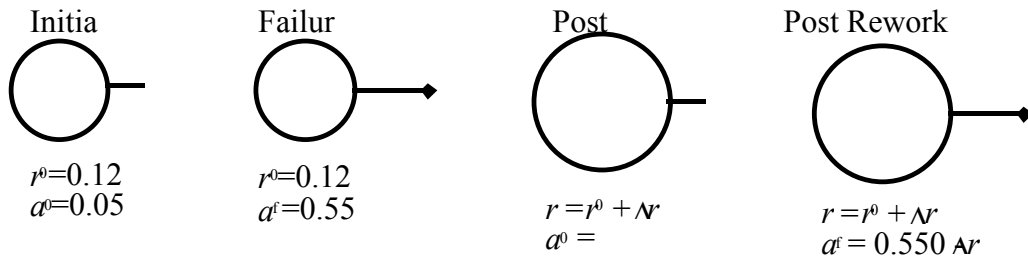


**Figure 9.5.1.** Three Stages in the Life of a Cracked Hole

As indicated in [Example 9.5.1](#), the larger the initial crack size, the shorter the life. Thus, the decision of choosing the initial flaw size after over-sizing is an important one - both for economy and for safety. For consistency of analysis with JSSG-2006 requirements, it is recommended that crack sizes be no smaller than that associated with initial manufacturing. An example problem is presented later in the section to consider the influence that the initial post rework crack size has on the remaining structural life. First, let us consider the influence that the reworked oversized hole has on life relative to that of the initial hole.

#### EXAMPLE 9.5.2 Effect of Rework Hole Size on Life

In this example, the blueprint diameter is 0.250 inches and the final crack length is 0.550. For comparative purposes, the initial crack length (both manufacturer's and post rework) is 0.050 inches and is assumed to be a through-thickness crack. The figure shows a description of the geometrical conditions both initially and post-rework.



#### Geometrical Parameters Associated with Blueprint and Post Rework Crack Configurations

Present a comparative life analysis that defines the effect of enlarging the 0.250 inch diameter hole to larger sizes during repair of hole crack damage. Allow the crack growth rate exponent  $p$  to vary from 2.5 to 3.5. Assess the effect of the exponent  $p$  on the results.

**SOLUTION:**

Since a comparative analysis is being conducted, it is not necessary to know the stress level nor the crack growth rate constant  $C$ , i.e., only those parameters that affect the integral  $I$  of Equation 9.5.3 need be considered. The table presents the results of the calculations where the lives have been normalized to the Blueprint life ( $I_{r=0.125}$ ), using

$$\frac{I_r - I_{r=0.125}}{I_{r=0.125}} * 100$$

where  $I_r$  is the value of Equation 9.5.3 for radius  $r$ .

Comparative Analysis To Determine the Effect Of Enlarging the Hole  
(Initial Crack Length = 0.050 Inch)

Initial Hole Radius (inch)	Rework Change in Radius (inch)	Final Crack Hole Radius (inch)	% Life Reduction		
			p = 2.5	p = 3.0	p = 3.5
0.125	0	0.125	0	0	0
0.125	1/64	0.140625	9%	10%	14%
0.125	1/32	0.15625	17%	20%	20%
0.125	3/64	0.171875	23%	27%	29%
0.125	1/16	0.1815	27%	31%	35%
0.125	5/64	0.203125	34%	39%	46%
0.125	3/32	0.21875	38%	43%	53%
0.125	7/64	0.234375	41%	46%	59%
0.125	1/8	0.250	44%	49%	66%
0.125	9/64	0.265625	47%	53%	72%
0.125	5/32	0.28125	50%	56%	77%